difference in the location of the zones measured. The resulting error will be inconsequential except when a boundary of a zone is in close proximity to the sun.

Equally as important as measurements of the relative intensity of diffuse radiation from the sun in horizontal sky zones are measurements of this intensity with reference to the sun's position, as was done by the Astrophysical Observatory, Smithsonian Institution,[1] and also photometrically by Dorno,[2] by Kimball and Hand,[3] and by others. In fact, a pyranometric measurement of the brightness of the sky in a restricted zone about the sun is an important factor in the *short method* of determining the solar constant now generally employed by the Smithsonian Institution.[4]

Our thanks are due to Professor Kalitin for calling attention to the importance of measurements that give the intensity of diffuse solar radiation received from different sky zones, which is dependent not alone upon the proximity to the sun but also upon the character of the ground surface over which the measurement is made (vegetation, sand, snow, water, etc.), and upon the water-vapor and dust content of the atmosphere.

[1] Moore, A. F., and Abbot, L. H. 1920. The Brightness of the Sky. Smithsonian Miscellaneous Collections, vol. 71, No. 4.

[2] Dorno, C. 1919. Himmelshelligkeit, Himmelspolarisation und Sonnenintensität in Davos, 1911 bis 1918. Veroff. des Preus. Met. Inst., No. 303, Abh. Band VI.

[3] Kimball, Herbert H., and Hand, Irving F. 1921: Sky-brightness and daylight illumination measurements. Monthly Weather Review, 49: 481. 1922: Daylight illumination on horizontal, vertical, and sloping surfaces. Monthly Weather Review, 50: 615.

[4] Abbot, C. G. 1919: Measurements of the solar constant of radiation at Calama, Chile. Monthly Weather Review, 47 :580. Abbot, C. G., and others. 1922: Use of the pyranometer in the measurement of the solar constant. Annals of the Astrophysica Observatory, 4: 79.

DORNO ON DAILY, YEARLY, AND SECULAR VARIATIONS OF THE SOLAR RADIATION AT DAVOS [1]

551.590.2

[Report made at the First International Conference on Light, Lausanne-Leysin, September 10-13, 1928]

By H. H. KIMBALL

In the introduction the following are enumerated as factors affecting quantitatively and qualitatively the amount of solar radiation and its variations.

First. Astrophysical and astronomical, which include—

(*a*) Solar variability;

(*b*) Earth's solar distance; and

(*c*) The astronomically determined length of day.

Second. Geographical and topographical, which include—

(*d*) Hours the sun is above the horizon (possible hours of sunshine), which is determined by the solar declination and the latitude of the place of observation.

(*e*) Topography: High mountains may cut off rays of sun while it is still above the horizon.

(*f*) Altitude: Since increase in height above sea level decreases the depth of atmosphere above the station, and also its water-vapor and dust content, and thereby decreases the atmospheric depletion of solar radiation.

(*g*) Character of the ground surface: Water, land (bare or covered with vegetation and kind of vegetation), snow, etc.

(*h*) Proximity of active volcanoes.

Third. Geophysical:

(*i*) Diffusion and absorption by the permanent gases, and by the ozone layer at an altitude of about 45 km., as well as through cosmical dust. The ozone layer, only 3 mm. thick under normal pressure, completely absorbs all radiation of shorter wave length than $290\mu\mu$.

(*j*) Fine cosmical dust and condensation products of various kinds, for the most part discharged by cathode and corpuscular rays of the sun, and which the northern lights (*aurora borealis*) reveal to us, must be present at great heights to a greater or less extent, depleting the solar rays to a variable degree.

Fourth. Meteorological—that is to say, the weather influences, extending to the upper cloud limit, or to about 10 to 12 km. of the 600 to 700 km. depth of the atmosphere:

(*k*) Principally determined by water in the atmosphere in gaseous (water vapor), liquid (water droplets), or solid (snow crystals) form. The invisible water vapor acts strongly to deplete the incoming radiation, partly through absorption of red and infra-red rays, partly through scattering, like other gas molecules inversely proportional to the fourth power of the wave length, or in connection with dust particles on which it collects, inversely as the square of the wave length.

On account of the great number and variety of factors influencing the spectral distribution and the intensity of solar radiation, the radiation climate of a place can not be accurately stated without radiation measurements and registration.

COMPILATION AND SCOPE OF EXISTING MATERIAL

With continuous measurements of the intensity of the total solar radiation covering 20 years, short gaps excepted, Davos has the longest record of any mountain observatory, and there is an older record at only a few places on the plains. The measurements were made partly with an Ångström compensation pyrheliometer and partly with secondary instruments controlled through comparison with the standard type. Continuous photographic records have been maintained since 1921 by means of the Davos pyrheliograph. The readings on the Ångström scale are reduced to the Smithsonian scale of 1913 by multiplying by 1.035.

Summaries of the measurements are given in both graphical and tabular form. Thus, in Table 1 are given hourly mean values (apparent time) of the intensity of solar radiation at normal incidence for each month of the year, expressed in gram calories per minute per square centimeter. The maximum midday mean is 1.495 in April, and the minimum, 1.354 in December, a range of 9.4 per cent. The maximum hourly mean is 1.516 at 1 p. m. in April and the minimum, 1.054 at 6 p. m. in June, a range of about 30 per cent. The low water-vapor content of the atmosphere in the spring as compared with the fall months, is the principal cause of the spring maximum of solar radiation intensity. Table 2, which gives annual means with the sun at altitude 30°, shows a maximum of 1.344 in 1921 and a minimum of 1.272 in 1925, with an annual average of 1.312. The corresponding annual average given by me for the years 1912–18 except that the monthly means were reduced to mean solar distance of the earth, is 1.35.[2]

[1] Tägliche, jährliche und säkulare Schwankungen der Sonnenstrahlung in Davos. (32 pp., 8 tables, 6 figs.) L'Expansion Scientifique Francaise. Paris, 1928.

[2] Kimball, Herbert H. 1927. Measurements of solar radiation intensity and determinations of its depletion by the atmosphere, with bibliography of pyrheliometric observations. Monthly Weather Review, 55: 161.

In the text reference is made to Lindholm's[3] determination of the depletion of solar radiation at Davos by atmospheric dust. It is interesting to note that for the years from 1914 to 1926, inclusive, the depletion by dust, including nuclei of condensation, averaged 4 per cent, that in 1921 it was 2.9 per cent, and in 1925 5.7 per cent, expressed in terms of the value of the solar constant as the unit.

This accounts for two-thirds of the difference between the maximum annual mean in 1921 and the minimum in 1925.

In the text attention is called to the atmospheric-optical disturbance following the eruption of Katmai Volcano in Alaska in June, 1912. In October of that month the deficiency in the total radiation was 18 per cent, which is the same as was obtained by me from seven widely scattered stations.[4] For August, 1912, I found the deficiency to be 22 per cent.

Figure 2 of Dorno's paper shows that the percentage loss by dust and condensation nuclei reaches a maximum of 6 per cent in May and a minimum of little more than 1 per cent from September to November. At least 2 per cent of the winter dust is attributable to local smoke.

Continuous records of the total solar radiation received on a horizontal surface from the sun and sky are obtained by means of a photographically recording pyrheliometer. The monthly and annual mean daily recorded totals are compared in Table 3 with corresponding means computed from the so-called *normal mean daily values*, or values obtained with cloudless skies, and the duration of sunshine as recorded by a Campbell-Stokes sunshine recorder. The computed daily totals are generally in excess of the recorded except for the months November, December, and January. The author points out that after a cold night the pedestal of the glass-sphere heliograph must become warm before the paper chart will begin to char. This may require an hour of sunshine with an intensity of 1.1 to 1.2 calories, while in summer intermittent sunshine is frequently shown as continuous. The maximum annual daily recorded total is 363 gr. cal. per cm^2 in 1927; the minimum, 312 in 1922. Here the effects of variations in annual cloudiness are apparent.

INTENSITY OF ISOLATED SPECTRAL BANDS

The spectrum was divided into bands as follows:

Ultra-red, 3,000$\mu\mu$ to 760$\mu\mu$.

Red, 760$\mu\mu$ to 630$\mu\mu$; mean optical center of gravity, 680$\mu\mu$.

Yellow, 630$\mu\mu$ to 560$\mu\mu$; mean optical center of gravity, 590$\mu\mu$.

Green-blue, 560$\mu\mu$ to 470$\mu\mu$; mean optical center of gravity, 518$\mu\mu$.

Violet, 470$\mu\mu$ to 400$\mu\mu$; mean optical center of gravity, 415$\mu\mu$.

Ultra-violet, 400$\mu\mu$ to 290$\mu\mu$; mean optical center of gravity, 315$\mu\mu$.

The different bands required different methods of measurement, as follows:

Ultra-red; heat measurements.

Red, yellow, green, photometric measurements.

Blue and violet, photoelectric measurements (potassium cell).

Ultra-violet, photoelectric measurements (cadmium cell).

[3] Lindholm, F. 1927. Über die Staubtrübung der Atmosphäre 1909 bis 1926, Beiträge zur Physik, 18: 127.

[4] Kimball, Herbert H. 1925. Variation in total solar radiation intensities measured at the surface of the earth. Monthly Weather Review, 52: 527.

Absorption screens were employed to isolate the different spectral bands except in the ultra-violet, where the cells employed determine the spectral limits included in the measurements.

The extraterrestrial solar spectrum energy curve derived from observations by Abbot and Fowle[5] on Mount Wilson was employed except in the ultra-violet, where the curve was computed by Planck's equation for radiation from a black body at a temperature of 6,000° absolute.

Solar spectrum energy curves for different hours on the 15th of December, March, June, and September, respectively, were computed from the coefficient of scattering for dry air, and the coefficients of scattering and absorption for water vapor with respect to the average water-vapor content of the atmosphere at Davos on the dates named. In the ultra-violet, for wave lengths 400$\mu\mu$ to 320$\mu\mu$ the transmission coefficients were computed from Rayleigh's equation, and for 320$\mu\mu$ to 290$\mu\mu$ coefficients determined by Fabry and Buisson were employed.

The energy in the different spectral bands was first expressed as a percentage of the energy in the total spectrum and then reduced to absolute units through the values of the total energy as measured by the pyrheliometer. Comparison of these computed percentages with percentages obtained from actual measurements in the spectral bands showed the best agreement in September, when, as already shown, the depletion by atmospheric dust is only 1 per cent. These percentages were therefore made the basis of the distribution of energy in the different spectral bands in other months, and also of the reduction of these percentages to calories. The results give in the ultra-red a maximum of about 50 per cent in December and a minimum of about 41 per cent near midday in June. In the red the variations with the season are slight, but there is an increase from about 17.6 to over 20 per cent from near midday to near sunrise and sunset. In other parts of the visible spectrum there is a decrease in the percentage with low sun, which is still more marked in the ultra-violet.

ULTRA-VIOLET RADIATION

Especial attention has been given at Davos to measurements of ultra-violet radiation in the solar spectrum, and to a study of its diurnal, annual, and secular variations. The diurnal and annual variations are shown in a table (4), which gives, in relative measures, the mean intensity of the ultra-violet at different hours of the day in the different months. The maximum occurs at midday in August, and the minimum for midday occurs in December. Another table (6) gives the shortest perceptible wave lengths registered at different hours on cloudless days for each month during the year, December, 1908–November, 1909.[6] The shortest perceptible wave lengths registered at any time is 293.9$\mu\mu$ between noon and 1 p. m. in April. The shortest measured in December is 306.2$\mu\mu$, between the same hours. Between 5 a. m. and 6 a. m. in August the shortest wave length measured is 320.2$\mu\mu$. It is apparent that the energy between wave lengths 302 and 298$\mu\mu$, which is most effective in biological reactions, is found only with high sun.

[5] Later and more accurate data on the extraterrestrial solar energy curve is given by these authors in Smithsonian Miscellaneous Collections, vol. 74, No. 7.

[6] This may be compared with monthly means for the same period, and including records obtained on days when cirrus clouds were present, given in *Strahlentherapie*, 1924, 18:734.

A systematic variation is noted in the absolute values of ultra-violet radiation from year to year. From a maximum in 1915–16 the value decreased to a minimum in about 1922, and again reached a maximum in 1926. The amplitude of the monthly variations (difference between the maximum and the minimum values, expressed as a percentage of the mean value for the period 1915–1927) varied from 34 per cent in April to 52.3 per cent in July.

Since the sun spot maximum occurred in 1917, and presumably also in 1928, with the minimum in 1923, it appears to the author as has been claimed by him since 1917, that the emitted solar radiation is the strongest at the beginning of solar activity, instead of at its maximum, and, analogously, the same is true for the minimum.

Meteorologists are greatly indebted to Professor Dorno for the excellent summary of his observational work on solar radiation at Davos. Unfortunately it is not possible in a brief review to bring out all the important information it contains.

My thanks are due to Mr. W. W. Reed for assistance in interpreting some passages in the German text.

SUMMARY OF THE PRESENT STATE OF OUR KNOWLEDGE OF THE DISTRIBUTION OF OZONE IN THE UPPER ATMOSPHERE

546.214

By G. M. B. DOBSON

[Boars Hill, Oxford, England, February 18, 1929]

By the very kind cooperation of several meteorologists we have been able to make a study of the distribution of ozone under different meteorological conditions by observations at six stations in northwest Europe during four months in 1926 and eight months in 1927. A full account of this investigation is published in the Proceedings, Royal Society of London,[1] together with the results of a year's observations at Montezuma, Chile, and the first values from a new series of observations begun at California,

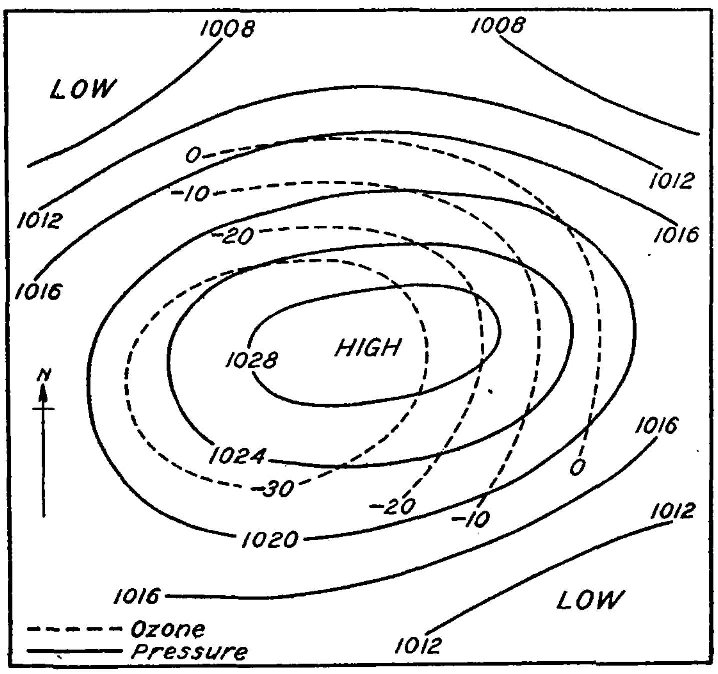

FIGURE 1.—Variation of ozone in connection with an anticyclone

Egypt, south India, and New Zealand. The most important results of these observations, together with those of other workers, are summarized below.

I. The variations of the amount of ozone with different meteorological conditions, with different times of year and with different latitudes is best seen by means of Figures 1, 2,[2] and 3.[3] Since the number of observations is small the diagrams must not be trusted for small details. (The average amount of ozone is equivalent to a layer of the pure gas some 3 mm. thick at 0° C. and 760 mm. Hg. The unit used in the diagrams is 0.01 mm. of the pure gas.)

II. The amount of ozone is more closely related to the conditions in the upper air than to those at the surface.

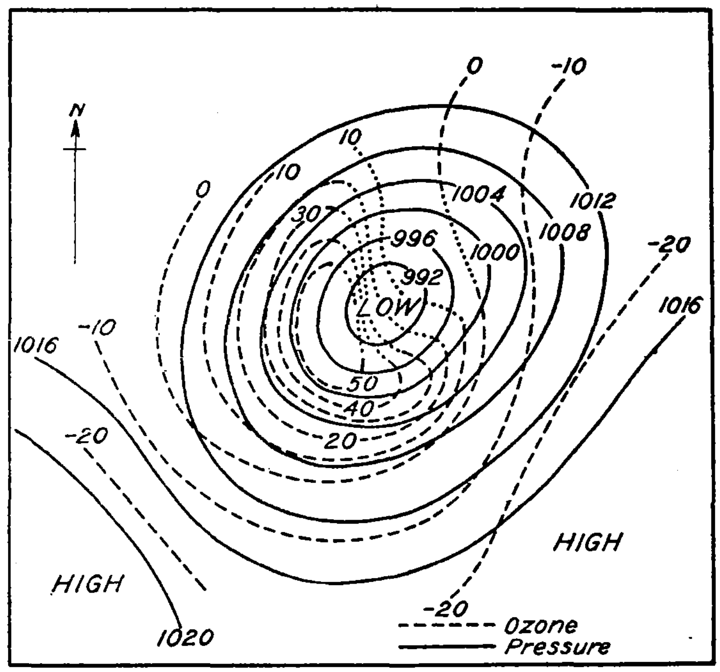

FIGURE 2.—Variation of ozone in connection with a cyclone

The connection with the conditions at 10 to 15 kms. is very close. There are not enough free-air observations to

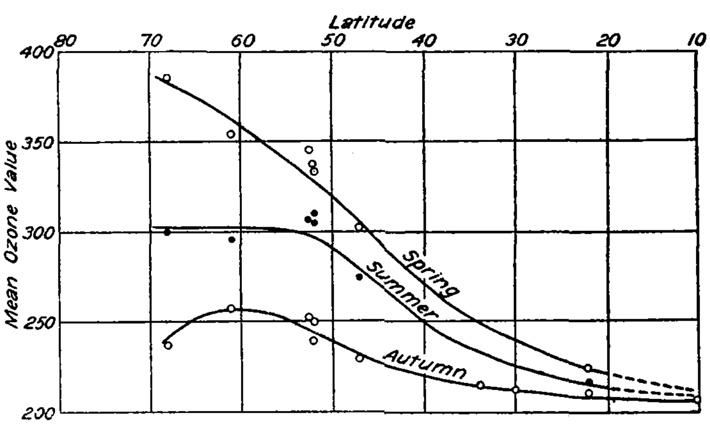

FIGURE 3.—Variation of ozone with season and latitude

show whether this connection is closer or less close at still greater heights. The amount of ozone is correlated:

[1] Dobson, Harrison & Lawrence. Roy. Soc. Proc. A, vol. 122, p. 456 (1929).
[2] Reproduced by permission of the Council of the Royal Society from the Proceedings.
[3] Reproduced by permission of Geh. Prof. Hergesell from Beit. Phys. d. f. Atmos.